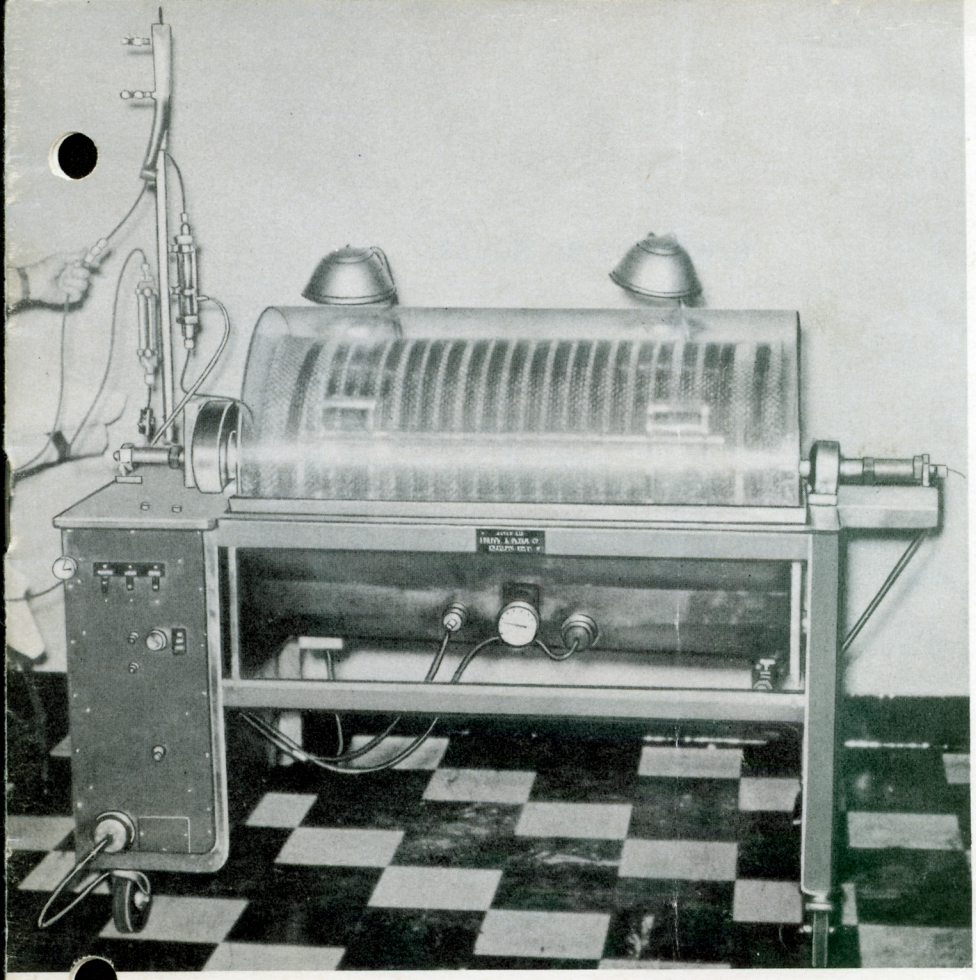



*The*

# KOLFF-BRIGHAM ARTIFICIAL KIDNEY

DESIGNED AND MANUACTURED BY

**EDWARD A. OLSON COMPANY · Union Street, Ashland, Massachusetts, U.S.A.**

*Telephone* TRINITY 5-4551

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*This brochure based on the following:*

# USE OF AN ARTIFICIAL KIDNEY

## III. Current Procedures in Clinical Hemodialysis

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## Introduction

TODAY, the Kolff-Brigham artificial kidney enjoys world-wide recognition and acceptance from the medical profession. Leading hospitals throughout the United States and in many foreign countries, including England, France, Belgium, Switzerland, South America and Japan have recorded outstanding life-saving achievements with this invention.

The United States Army Medical Corps used the Kolff-Brigham artificial kidney sucessfully at front line hospitals during the Korean War for patients suffering from potassium intoxication following massive emergency blood transfusions. An Army Captain poisoned by carbon tetrachloride inhalation with resulting kidney failure was cured with this unit. For 26 days the artificial kidney substituted for the kidneys of an Army Corporal who had suffered a crushed back and perforated intestines in a severe auto accident. At the end of the 26 day period, the patient's own kidneys were able to resume their normal function. A milestone in medical history — transplanting of kidneys in identical twins — has been made possible by the use of this hemodialyzer.

Equally important as successful case histories is the record of dependability and safety that the Kolff-Brigham artificial kidney has enjoyed since its introduction in 1948.[1-3] The Peter Bent Brigham Hospital in Boston, Massachusetts, has used the artificial kidney over 530 times on patients with varying degrees of renal difficulties. To date, no death attributable to the hemodialytic procedure has occured, although hemodialysis has been accomplished in patients under 4 years of age, over 70 years of age, and in patients with such serious problems as extensive third-degree burns, peritonitis, shock, coma, congestive heart failure, profound anemia, and recent myocardial infarction.

The technique of circulating blood extracorporeally for the purpose of dialyzing out metabolites present in abnormally high concentrations in body fluids in acute and chronic renal failures presents may problems. Factors that must be taken into account are: clotting, hemolysis, bleeding, exsanguination, plethora, adequacy of blood flow through the apparatus, leakage, sepsis, air embolism, electrolyte and water balance, temperature control, and comfort of the patient. Experience in the laboratory with these problems has led to technical modifications which may be useful to those engaged in extracorporeal blood circulation in general and hemodialysis in particular. This report deals with technical changes designed to make the procedure of clinical hemodialysis with the Kolff-Brigham artificial kidney safer, simpler, more efficient, and less costly in time and material.

## Materials and Methods

*Technical Information for Clinical Hemodialysis* — The Kolff-Brigham hemodialyzer (Fig. 1) receives blood from the radial artery through a rotating coupling to a dialyzing membrane consisting of a long cellophane tube wound spirally on a drum rotating in a bath. From the cellophane tubing blood passes through a distal rotating coupling and return pump to a reservoir, clot-catcher, and bubble trap from which the blood returns to a forearm vein. It is obvious that the dialyzing area should be large and the volume of blood in the apparatus small in order to increase dialyzing efficiency and minimize the volume of blood required to

fill the apparatus prior to dialysis. Blood should contact hemorepellent surfaces only. For ease and speed of assembly and to reduce opportunity for contamination, the number of parts and connections in the circuit should be minimal. These parts should withstand autoclaving after assembly without distortion of finely machined surfaces. With these aims in mind, the following changes have been made in the apparatus previously described.[1]

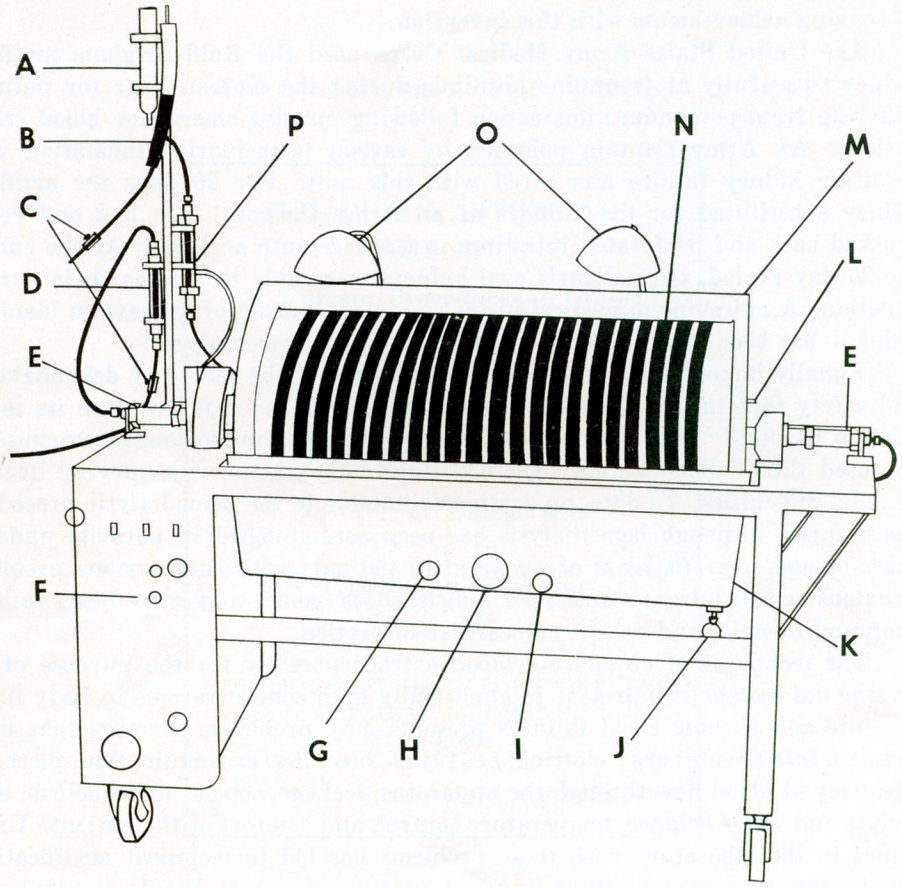


Fig. 1. — Kolff-Brigham hemodialyzer. *A*, filling burette; *B*, pressure burette; *C*, metering clamp; *D*, flow meter; *E*, rotary couplings; *F*, control panel; *G*, thermoswitch; *H*, thermometer; *I*, pan light; *J*, filling and drain connections; *K*, bath pan; *L*, carbon dioxide connection; *M*, plexiglass hood; *N*, cellophane tubing on drum; *O*, hood lamps; *P*, blood pump.

*Tubing and Cannulae.*—The nonautoclavable polyethylene cannulae, rubber connectors, and large bore plastic tubing have been replaced by smaller (3/16 inch internal diameter, the diameter of all other orifices in the apparatus) polyvinyl chloride tubing. The arterial and venous leads are prepared in advance by drawing out the ends into appropriately sized cannulae after softening and deplasticizing in mineral oil at 175° C. for a few minutes. The cannulae are deplasticized to a hardness sufficient to prevent crushing by ligatures. A gum rubber sleeve (1 inch long, ¼ inch internal diameter 1/16 inch wall) is slipped over the end of each cannula just before use to provide a self-sealing area for blood sampling and intravenous medication. Cannulae are made sufficiently long to allow the surgeon to trim them

to the desired length and cut a suitable bevel. Excessively long cannulae. will introduce excessive pressure drop and decrease blood flow. Cannulae with sharp or ragged edges may strip the intima and become blocked.

*Couplings.*—The rotating couplings (Fig. 2) are lined with Kel-F,* an extremely stable plastic resisting distortion during autoclaving and wear during the operation. The plastic parts are encased in a stainless steel shell revolving in a bronze bushing. The width of the rotating plastic face has been considerably reduced (9/32 inch to 1/32 inch) to increase surface loading. Blood leakage at the coupling has been completely eliminated. In order to stabilize the rotating member of the coupling, it has been lengthened, its bearing surfaces separated to approximately three and one-half times its diameter, and the loading spring replaced by a beryllium copper spring washer.

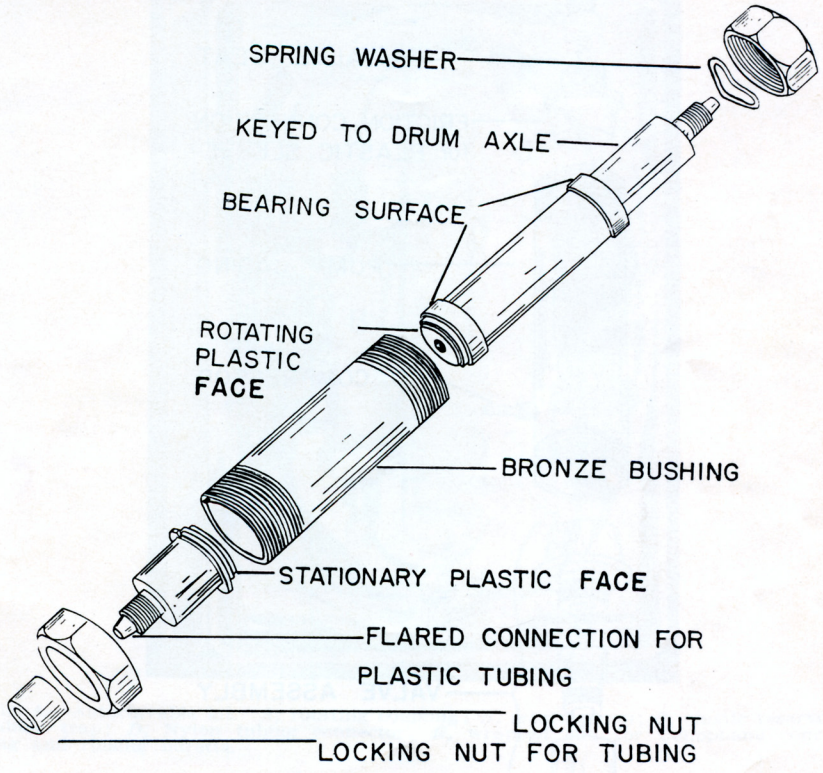


Fig. 2.—Exploded view of rotating coupling.

*Connections.*—3/16 inch interval diameter polyvinyl tubing runs through the hollow axle of the drum and connects the coupling with the cellophane. A ½ inch length of ¼ inch I.D. polyvinyl tubing slipped over one end and cemented with cyclohexanone gives a firm autoclavable anchor for tying the cellophane tubing over the polyvinyl tubing with two ¼ inch cotton tape ties. The polyvinyl tubing is attached to all parts with flare-type connections (Fig. 4, *D*), the tubing being pressed over a slight flare and held in place with a locking nut. This connection gives a uniform lumen with minimal turbulence.

*Cellophane.*—138 feet of 23/32 inch diameter lay-flat cellophane tubing (22,000 sq. cm. of dialyzing area) is wound tightly about the drum. Any slack in winding or stretch during operation accumulates at the distal end of the drum where it is taken up by a spring-loaded support rotating about the main axle. The cellophane area above the surface of the bath is

*A tetrafluoroethylene plastic.

effective for dialysis because of the considerable amount of bath fluid which is carried up with the drum and drains back to the bath when the drum rotates at 26 r.p.m. Complete immersion of the drum, if technically possible, would destroy the pumping action of the helically wound cellophane loops. Considerably less than the usual extent of drum immersion still results in efficient dialysis, as is shown in Table I.

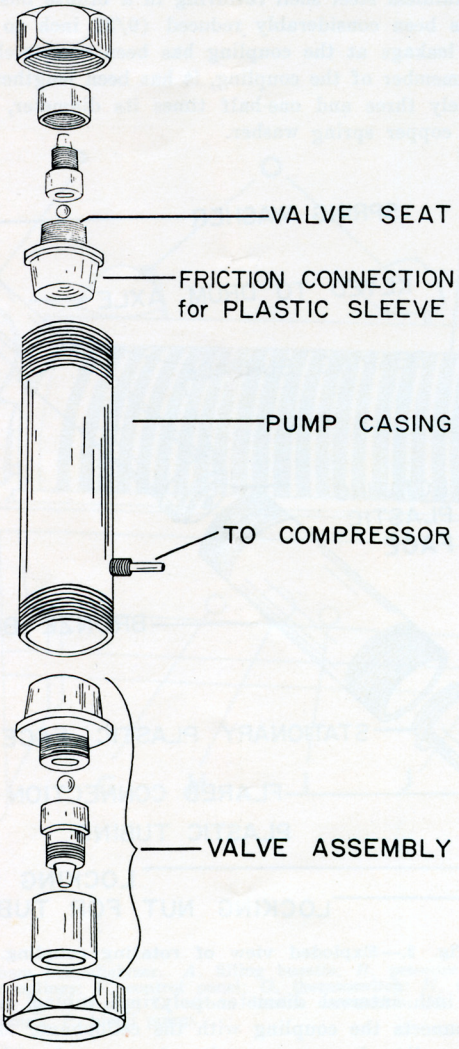


Fig. 3.—Exploded view of return pump. The flexible plastic tubing lying within the pump casing has been omitted from this drawing.

*Return Pump.*—Three forces propel blood through the apparatus. Arterial pressure serves only to propel blood through the arterial lead, flow meter, and proximal rotating coupling to the first cellophane loop. Thereafter, blood is propelled, independent of arterial pressure, by (a) the Archimedes screw principle of the helically wound cellophane tube, and (b) a pump (Fig. 3) returning blood from the terminal loop through a sealed clot and air bubble trap to a peripheral vein. The return pump is a flexible polyvinyl tube 1 inch in diameter surrounded by a rigid Kel-F casing with a check valve at each end. The tube

is alternately distended and collapsed by negative and positive pressure from a modified refrigerator-type compressor, stroke 1½ inch, bore 1½ inch, in phase with the rotating drum and begins suction when the distal end of the Cellophane tube is in its lowest position and thus full of blood. Any continuously acting pump, like the Beck pump, is unsuitable since, by creating suction when the terminal Cellophane loop is relatively empty of blood, it tends to draw air in through the interface of the distal rotating coupling. Such does not occur with a correctly synchronized, intermittently acting pump such as the one described. The pump parts are constructed of stainless steel, Kel-F, and polyvinyl chloride. Blood contacts hemorepellent surfaces only.

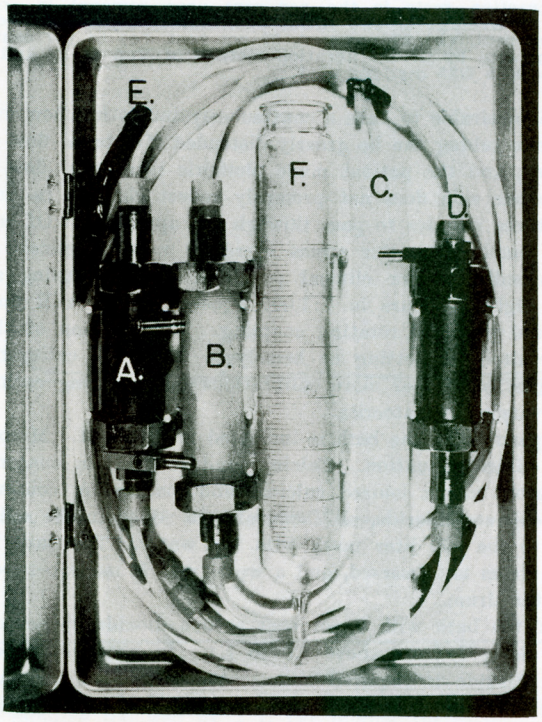


Fig. 4.—Autoclavable kit. *A*, rotating coupling; *B*, return pump; *C*, plastic reservoir, clot and bubble trap; *D*, Nylon tubing connector; *E*, wrapped end for Cellophane connection; F. filling and rinsing burette.

*Clot and Bubble Trap.*—Blood from the return pump enters a venous reservoir serving also as a clot and bubble trap. This is constructed of 1 inch diameter (0.032 inch wall) polyvinyl chloride tubing heat sealed at the ends. Glass beads act as clot catchers. The 3/16 inch tube at the top is clamped off when a satisfactory blood level and air cushion are established. Through this opening blood or air can be added or removed from the system. This arrangement affords a self-regulating positive pressure venous return since increased inflow from the pump tends to increase pressure within the reservoir, while reduced inflow results in progressively decreasing outflow as the pressure in the reservoir falls. The venous cannula is connected to the discharge side of the trap.

*Autoclavable Kit.*—All the above parts are autoclavable. The rigid plastic parts (connectors, couplings, pump valves, and casing) are made of Nylon or Kel-F and are reused. The polyvinyl parts are disposable. Except for the Cellophane and the flow meter, all the blood conducting parts, together with a glass burette for rinsing and filling the apparatus before dialysis, are assembled and autoclaved in an 11 inch by 16 inch aluminum container.

TABLE I. EXTRACTION RATIOS AT VARYING DEGREES OF DRUM IMMERSION

| | % OF DRUM CIRCUMFERENCE IMMERSED | UREA EXTRACTION RATIO |
|---|---|---|
| A. Bath fully raised | 40% | 90% |
| B. Bath raised half-way | 25% | 88% |
| C. Bath touching | 12% | 85% |

Osmolarity of urea solution and glucose bath solution = 33 mos. per liter

Urea solution = 89.5 mg. per cent urea nitrogen

Flow = 200 ml. per minute

Urea solution was dialyzed against an isosmotic glucose bath at three levels of drum immersion. Urea extraction ratio is the per cent urea removal in one passage through the apparatus and is an average of two ratios determined at each level of drum immersion: (a) 92 per cent, 88 per cent, (b) 87 per cent, 89 per cent, (c) 84 per cent, 86 per cent, Urea was determined in duplicate by urease aeration method of Van Slyke and Cullen.[4] Variation of averages of duplicates is 0.33 mg. per cent.

*Flowmeter.*—It is desirable to have a continuously indicating flow meter on the arterial side since the Cellophane tubing can be greatly distended if arterial flow exceeds venous flow for any length of time, and the patient made plethoric if arterial flow slows or stops. A flow meter on the venous side does not promptly reflect changes in arterial flow because blood requires about three minutes to pass through the apparatus. Of several types of flow meters considered, a simple rotameter seems currently most practical, giving an accuracy (within 15 per cent) sufficient for clinical purposes. We are using a lucite rotameter* sterilized by soaking eighteen hours in 1:1,000 aqueous Zephiran R and inserted between the arterial cannula and proximal rotating coupling. The addition of the rotameter to the apparatus has not resulted in clotting or hemolysis. A rough calibration chart has been prepared by a mass plot of two or more calibrations taken during each dialysis on several patients with widely varying hematocrits.

*Bath.*—The composition of the bath is indicated in Table II. Minor changes are made depending upon the clinical situation. Calcium and magnesium concentrations have been reduced to approximately match ionized calcium and magnesium concentrations in normal plasma. Except for calcium chloride, all chemicals are added in the solid form as the bath is being brought up to the 100 liter mark with tap water. The bath is then raised until the lower half of the drum is immersed, and a water seal is made between the bath and the lucite hood covering the drum.

Equilibration of the bath with 5 per cent carbon dioxide 95 per cent oxygen mixture theoretically reduces the pH from above 8.0 to 7.4. In practice, however, a greater concentration of carbon dioxide is required because the volume of air under the hood which must be displaced by the carbon dioxide mixture is over 100 liters, and because some leakage of gas occurs around the openings in the hood for the drum axle. Since the bath fluid is well agitated by the rotating drum and continuously being carried up over the drum as a thin film, admitting the carbon dioxideoxygen through a bubbler in the bath offers little advantage over a simple connection in the hood. Change in the bath pH during equilibration with 10 per cent carbon dioxide 90 per cent oxygen mixture is shown in Fig. 5. Calcium chloride, previously weighed out in individual paper containers and stored in a desiccant-containing cannister, is dissolved in approximately 50 ml. of warm water and added through one of the apertures in the plastic hood after the bath has been equilibrated for fifteen minutes with carbon dioxide.

TABLE II. BATH COMPOSITION

| | GMS/100 L | MOS/L | MEQ/L |
|---|---|---|---|
| NaCl | 660 | 226 | 113 |
| $NaHCO_3$ | 225 | 54 | 26.8 |
| KCl | 30 | 8.0 | 4.0 |
| $MgCl_2 \cdot 6H_2O$ | 10 | 1.5 | 1.0 |
| $CaCl_2 \cdot 2H_2O$ | 18.5 | 3.8 | 2.5 |
| Glucose | 200 | 10.0 | $Na^+ = 140$ |
| | | 303.3 | $Cl^- = 120$ |

*Furnished by Mr. Harry Barker of the Westinghouse Electric Corporation.

In practice we no longer attempt to match bath osmolarity with plasma osmolarity in each patient by the addition of a calculated amount of glucose. The bath is made up to osmolarity equivalent to normal plasma. No large or consistent weight change results during dialysis.

Following dialysis the stainless steel bath tank and drum are washed with tap water. The use of detergents and antimicrobial agents has been eliminated.

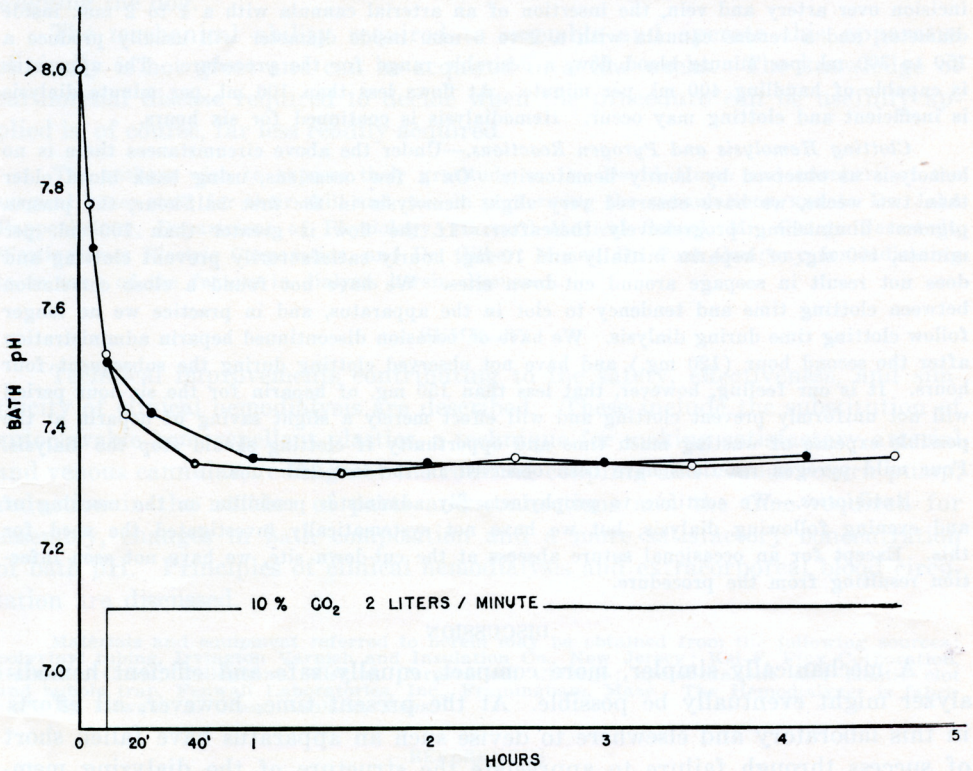


Fig. 5.—Change in bath pH during equilibration with 10 per cent carbon dioxide at 15 L per minute for ten minutes followed by 2 L per minute thereafter. The pH of bath was determined at 38.5° C. by the method of Hastings and Sendroy.[5]

*Procedure.*—Clotting time is determined, and 2 pints of blood are typed and cross-matched on the day before dialysis. On the morning of dialysis, the patient is sedated and weighed. Food is withheld. The autoclaved parts are attached to the machine. The Cellophane, which has been previously soaked overnight in water on a reel to remove the glycerine softening agent and boiled in two thirty-minute washes in an automatically timed bath, is wound on the drum. Fifty mililiters of bank blood diluted with saline are run in from the filling burette to test the system for leaks. The system is then flushed with 3 liters of saline and filled with 500 to 700 ml. of citrated bank blood. The bath is made up and kept at 39° C.

Meanwhile, the surgeon, having exposed the radial artery and a forearm vein, cannulates the vein, and through the cannula injects an appropriate amount of heparin, usually 100 mg. He then cannulates the artery and collects arterial samples for chemical analysis. The venous and arterial leads are allowed to fill with blood, are connected to the apparatus, and dialysis begins. Adjustable clamps on arterial and venous leads balance inflow and outflow. Distention of the terminal cellophane loop and change in blood level in the clot and air

bubble trap are early indications of imbalance between arterial and venous flow. Venous flow frequently lags behind arterial flow at the beginning of dialysis because cool blood in the return tubing may cause a transient venospasm. This can be relieved by the local application of heat. Thereafter venous flow improves and arterial flow is usually the limiting factor.*

Arterial flow depends in part upon the caliber, length, and position of the cannula, which in turn depend upon the nature of the vessel and the surgical skill employed. A 1½ to 2 cm. incision over artery and vein, the insertion of an arterial cannula with a 1 to 2 mm. inside diameter, and a venous cannula with a 2 to 3 mm. inside diameter will usually produce a 150 to 300 ml. per minute blood flow, a desirable range for the procedure. The apparatus is capable of handling 400 ml. per minute. At flows less than 100 ml. per minute dialysis is inefficient and clotting may occur. Hemodialysis is continued for six hours.

*Clotting Hemolysis and Pyrogen Reactions.*—Under the above circumstances there is no hemolysis as observed by hourly hematocrits. On a few occasions, using bank blood older than two weeks, we have observed very slight hemolysis in the first half-hour, the plasma pigment diminishing progressively thereafter. If the flow is greater than 100 ml. per minute, 100 mg. of heparin initially and 10 mg. hourly satisfactorily prevent clotting and does not result in seepage around cut-down sites. We have not found a close correlation between clotting time and tendency to clot in the apparatus, and in practice we no longer follow clotting time during dialysis. We have on occasion discontinued heparin administration after the second hour (120 mg.) and have not observed clotting during the subsequent four hours. It is our feeling, however, that less than 150 mg. of heparin for the six-hour period will not uniformly prevent clotting and will effect merely a slight saving of heparin at the possible expense of wasting much time and opportunity if clotting should stop the dialysis. Four mild pyrogen reactions have been observed in the last 165 runs.

*Antibiotics.*—We continue to prophylactically administer penicillin on the morning of and evening following dialysis, but we have not systematically investigated the need for this. Except for an occasional suture abscess at the cut-down site, we have not seen infection resulting from the procedure.

## DISCUSSION

A mechanically simpler, more compact, equally safe and efficient hemodialyzer might eventually be possible. At the present time, however, all efforts in this laboratory and elsewhere to devise such an apparatus have fallen short of success through failure to appreciate the structure of the dialyzing membrane, the principles of diffusion through semipermeable membranes, and the hydraulic principles of flow across the surface of the membrane. Dialyzing efficiency is dependent not only on the ratio of the membrane area to which a given volume of blood is exposed, but also on membrane thickness, total pore area per unit area of membrane and, for larger molecules, on the average radius of the pores of the membrane. It is also most significantly dependent upon film resistance resulting from the laminar flow of bath liquid and the more viscous blood adjacent to the membrane. In the apparatus originally devised by Kolff, the factor of the film resistance is ingeniously minimized by the rapidly rotating drum to an extent not yet achieved by mechanically simpler stationary hemodialyzers.

In attempting to reduce the size of the apparatus for portability and bedside use, one must recognize, however, that the procedure is by and large an elective one, seldom being required on such short notice as a few hours. As

*Wolf and associates[6] has shown that the volume of blood in the Cellophane loops varies with blood flow through the apparatus.

such this procedure deserves its own special room. Considering the surgical equipment and space required for arterial and venous cannulation, carbon dioxide cylinders, cellophane boiler, sink and storage space for chemicals and sterilized equipment, it is obvious that, at least for a hemodialyzer built on the Kolff principle, reducing the size of the unit eventually reaches the point of the tail wagging the dog.

The mechanical ability required to assemble and operate this apparatus clinically is not great and can be acquired in a few weeks. The knowledge of cardiorenal disease required to decide when the procedure can be usefully applied is, of course, far less readily acquired.

The authors wish to express their gratitude to Dr. David Hume and members of the surgical house staff for their skill and care in performing the cannulations, and to Dr. John Pappenheimer, Department of Physiology, Harvard Medical School, Mr. George Jernstedt, Westinghouse Electric Corporation, and Dr. Gilbert Monet, Du Pont Company for indicating to us some of the factors in dialysis herein discussed.

## SUMMARY

Technical improvements contributing to the safety, effectiveness, and simplicity of clinical hemodialysis are described. These include the substitution of autoclavable hemorepellent plastics, a technique for making satisfactory arterial and venous cannulae, redesign of the rotating coupling and venous return pump, reduction in the number of parts and connections and the time required for assembly, changes in bath composition and a more satisfactory concentration of bath pH. Principles of clinical hemodialysis and extracorporeal blood circulation are discussed.

Materials and equipment referred to herein may be obtained from the following sources: polyvinyl tubing, Irvington Varnish and Insulation Co., New Jersey; Kel-F, Plax Corporation, Hartford, Conn., Cellophane, Visking Corporation, Chicago; cyclohexanone and plastic clot and bubble trap, Fenwall Laboratories, Inc., Framingham, Mass. The Hemodialyzer is fabricated by Edward A. Olson, Ashland, Mass.

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## DIGEST OF SPECIFICATIONS
## FOR
## THE KOLFF-BRIGHAM ARTIFICIAL KIDNEY

1. Machine is of stainless steel construction throughout.
2. Requires 220 volt (50 or 60 cycle) single phase current. (Special wall plug furnished). Purchaser must specify if 50 or 60 cycle single phase current available at installation site.
3. Electrical connections, motors, compressor which operate the heart action pump are all enclosed in cabinet at front of machine.
4. All of the blood-handling equipment (plastic tubing, pump, and couplings) are made of plastics and can be steam sterilized or autoclaved. The Lucite flow meter cannot be steam sterilized.
5. Bath heated by two 1000 watt heaters under the pan. Temperature controlled by a thermoswitch and mercury relay.
6. Pan raised and lowered by separate ratio motor and has limit switches at top and bottom of its travel.
7. Pan contains thermometer for checking bath temperature. Pan pilot lights indicate when heaters are operating. Pan has draining and filing connections. Special pan light permits observation of solutions at all times.
8. Two lamps on hood prevent fogging of the plexiglass.
9. Drum revolves by means of a chain driven by a ratio motor. Clutch for drum provided. When disengaged, clutch allows drum to be revolved freely for making cellophane connections.
10. Revolving drum, of stainless screening, is in a fixed position permitting the testing of the cellophane and changing of bath solution without disturbing tubing containing blood.
11. Guards provided for pump indexing mechanism and for the chain drive sprocket to the drum.
12. A special cellophane boiler with reels and a reeling device for the cellophane, as well as a special sterilizing pan in which the plastic tubing, pump, and rotary couplings may be autoclaved, are furnished with the machine. All of the sterile component parts used in a run can be assembled on the machine in approximately the time required by the surgeon to make his cut-downs.
13. Shatterproof rotary couplings.
14. Approximate floor space required — 3′ x 5′.

## CONCLUSION

Hospitals using these machines successfully have taken advantage of the research program at the Peter Bent Brigham Hospital in Boston, Massachusetts, by sending selected personnel to this hospital for training in the operation and use of these units.

Experience has shown that the Kolff-Brigham artificial kidney requires practically no servicing despite years of continuous use. Even more important, when used extensively, this machine because of its low operating and supply costs has proved to be more efficient and less expensive — average time required for hemodialysis is 6 hours.

Accessories vital to the operation of the Kolff-Brigham artificial kidney, such as plastic tubing, specially packaged cellophane, pump membranes, etc., are stocked and available from the manufacturing company.

Upon request, the Edward A. Olson Company will be glad to furnish names of other hospitals using the Kolff-Brigham artificial kidney with outstanding success.

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